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# Figure 1b: *Correct attachment of tubing*
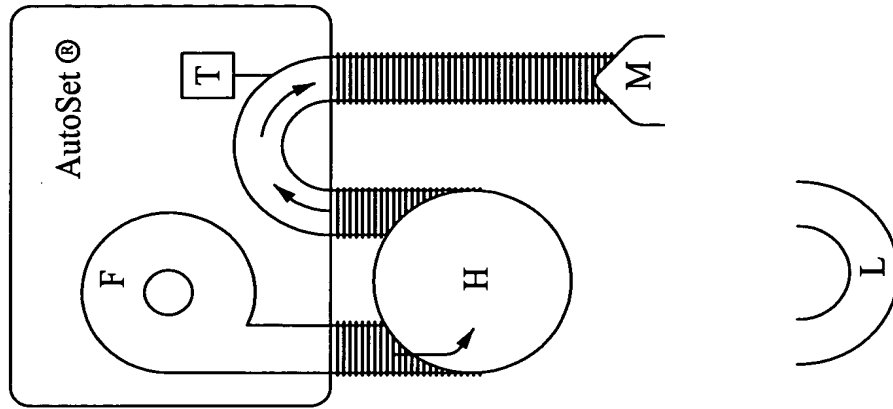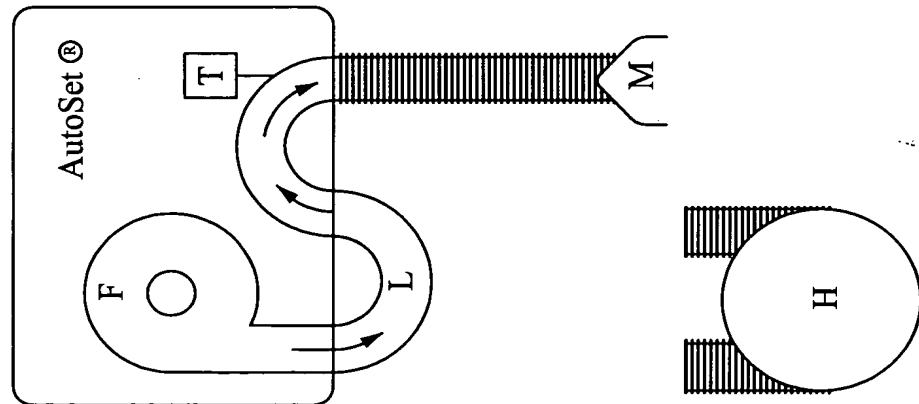


# Figure 1a: *Correct attachment of tubing*

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Figure 1d: *Incorrect attachment of tubing*
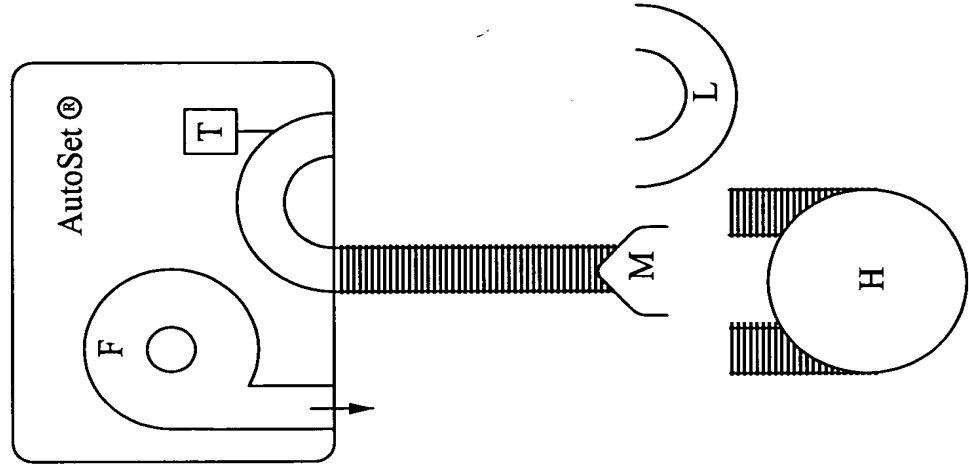
Figure 1c: *Incorrect attachment of tubing*

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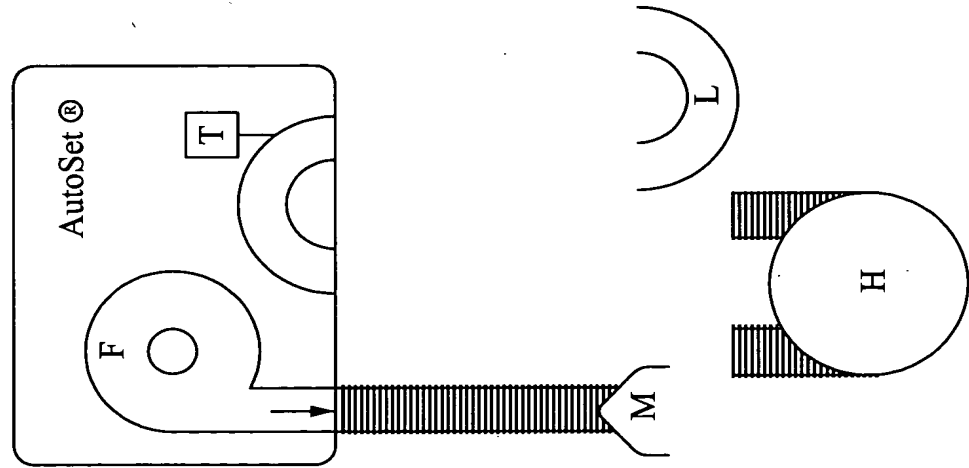
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**Figure 2:** *CPAP apparatus*

Measured
pressure, $p$

Upper allowed limit

$\zeta_{f2}$

$\zeta_d$

$\zeta_{f1}$

Lower
allowed limit

Measured flow, $f$
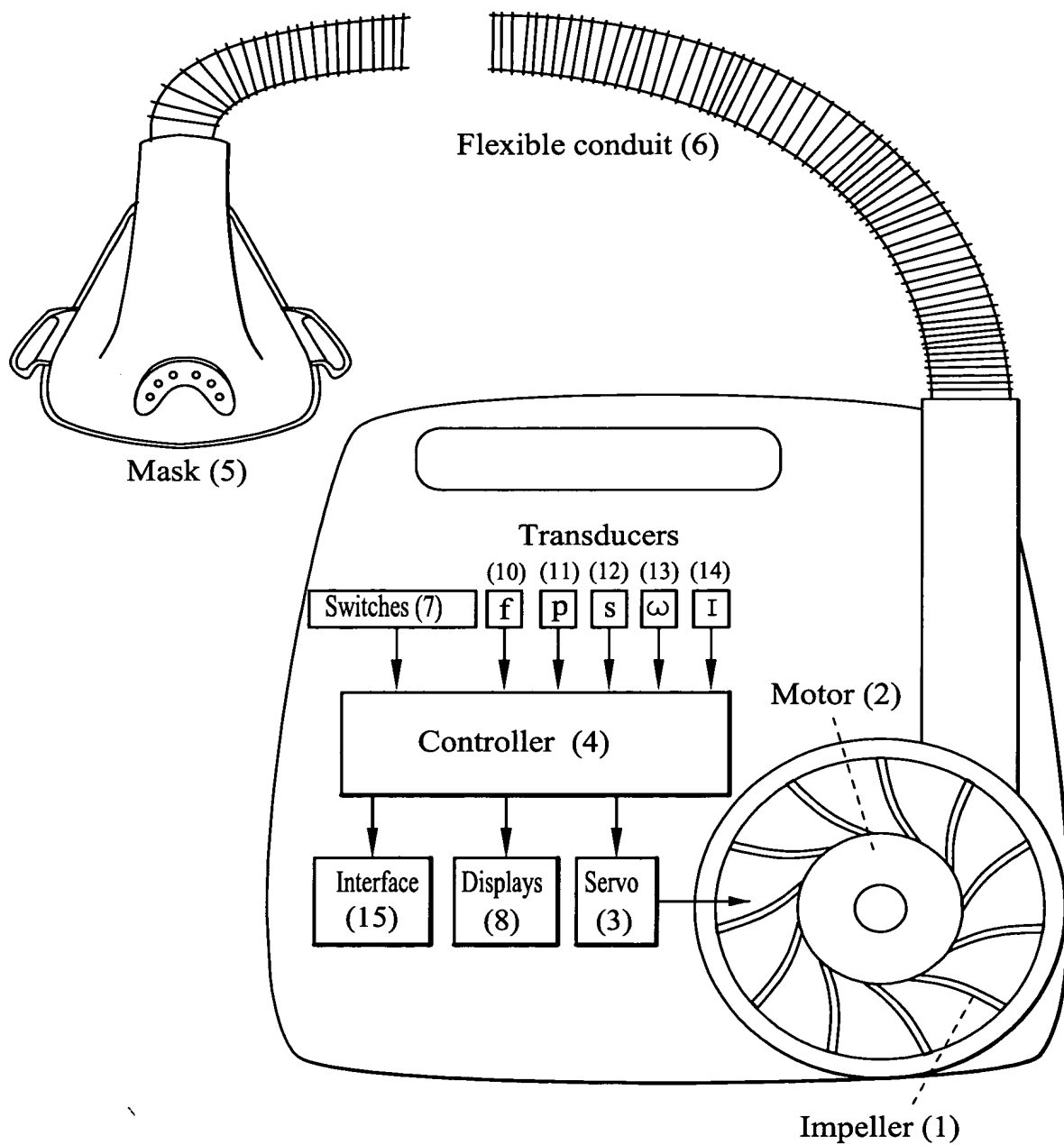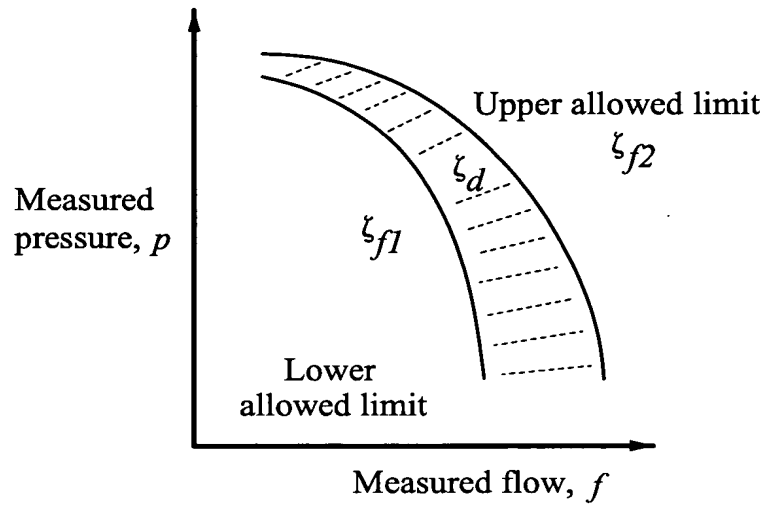
## Figure 3a: *High motor speed (ω) operation*

Measured
pressure, $p$

Upper
allowed limit

$\zeta_{f2}$

$\zeta_d$

$\zeta_{f1}$

Lower
allowed limit

Measured flow, $f$
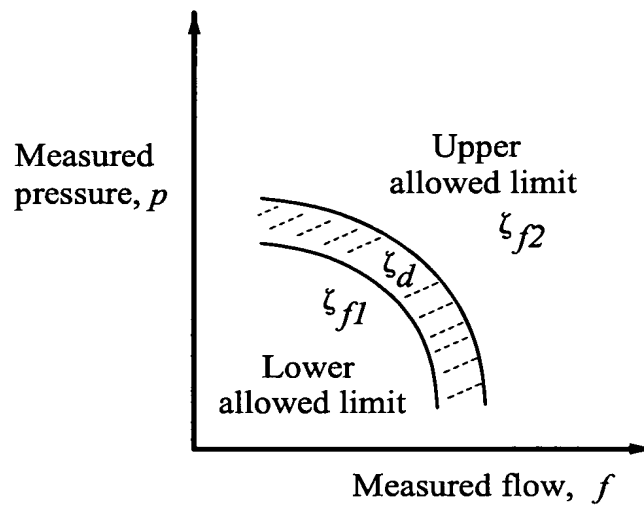
## Figure 3b: *Low motor speed (ω) operation*

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```
                    ┌──────────────┐
                    │    Start     │
                    └──────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │  (41) Calculate hardware │
              │    parameter #1, #2, ... │
              └──────────────────────────┘
                           │
                           ▼
  ┌─────────────────────────────────────────────────────┐
  │              ┌──────────────────────────┐            │
  │  ◄───────────│  (42) Calculate software │──────────► │
  │              │    parameter #1, #2, ... │            │
  │              └──────────────────────────┘            │
  │                          ▲                            │
  │   ┌──────────────────┐   │   ┌──────────────────┐     │
  └──►│ (44) Normal      │   │   │ (43) Fault       │◄────┘
      │ processes        │──►│◄──│ diagnosis        │
      └──────────────────┘   │   │ processes        │
                             │   └──────────────────┘
                             ▼
                 ┌──────────────────┐
                 │ (45) Generate    │
                 │ hardware         │
                 │ instructions     │
                 └──────────────────┘
                           │
                           ▼
                    ┌──────────────┐
                    │     End      │
                    └──────────────┘
```
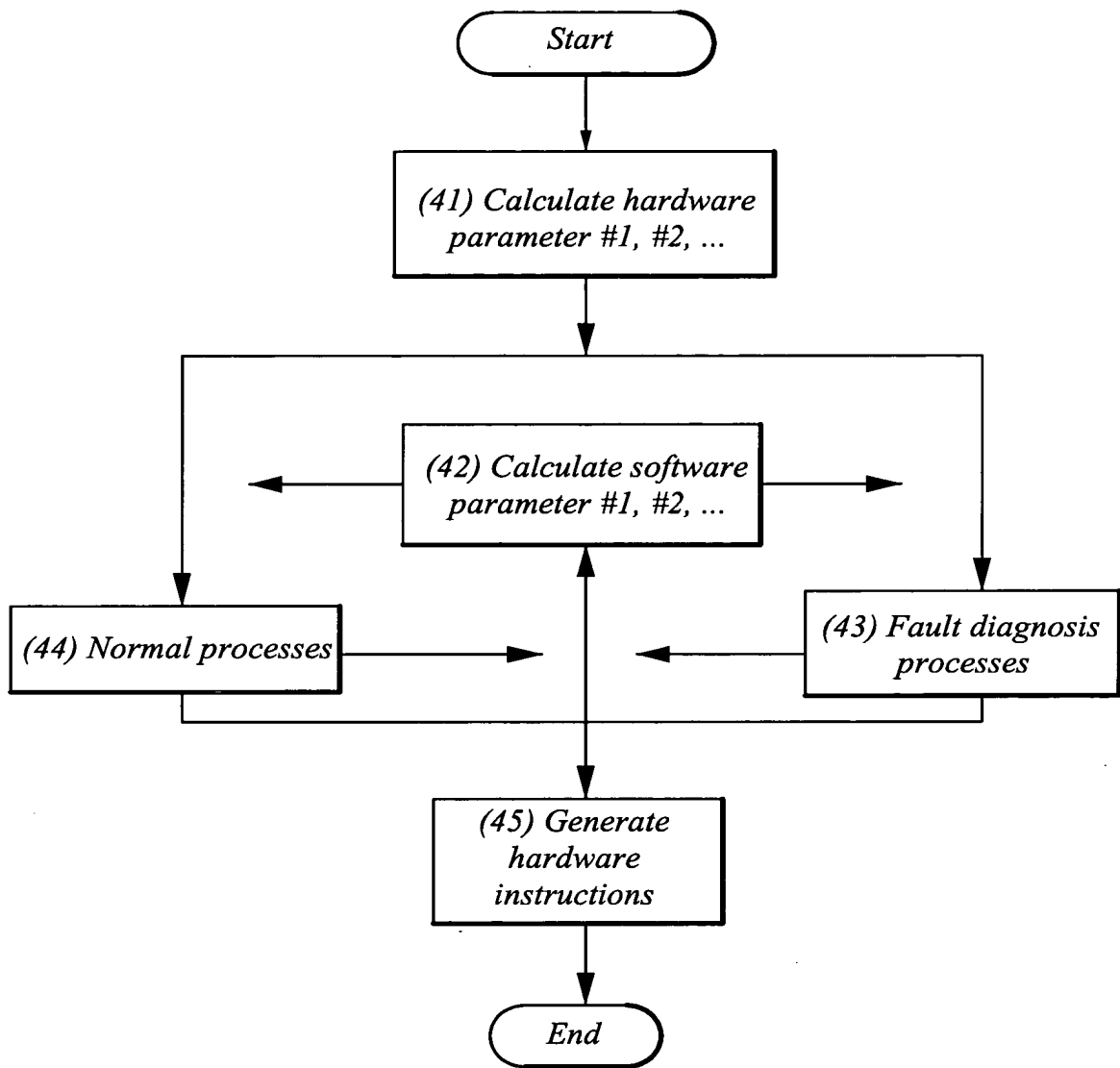
Figure 4: *Fault diagnosis implemented in overall software processes*

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Fault region: Pressure
transducer stuck high

Measured
pressure (cm $H_2O$)

15.0

Fault region: Pressure
transducer stuck low

2.0

4.5        12.0

Motor speed (krpm)

**Figure 5:** *Pressure transducer fault regions*

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Pressure transducer
stuck low     (66)

Counter > 0.3 sec
(65)

Increment counter
while true;     (64)

Reset counter
while false

(63)

ω > 12 krpm
(61)
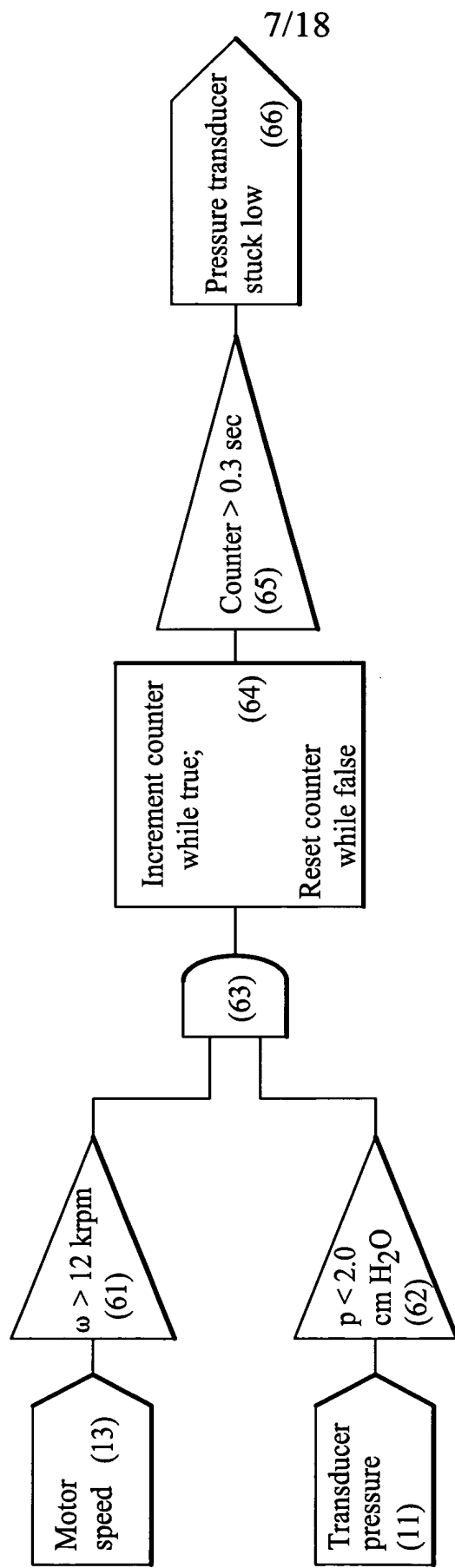
p < 2.0
cm H$_2$O
(62)

Motor
speed   (13)

Transducer
pressure
(11)

Figure 6: *Detect Pressure Transducer Stuck Low*

Pressure transducer
stuck High    (76)

Counter > 0.3 sec
(75)

Increment counter
while true;    (74)

Reset counter
while false

(73)

ω < 4.5 krpm
(71)

p > 15.0
cm H2O
(72)

Motor
speed   (13)

Transducer
pressure
(11)
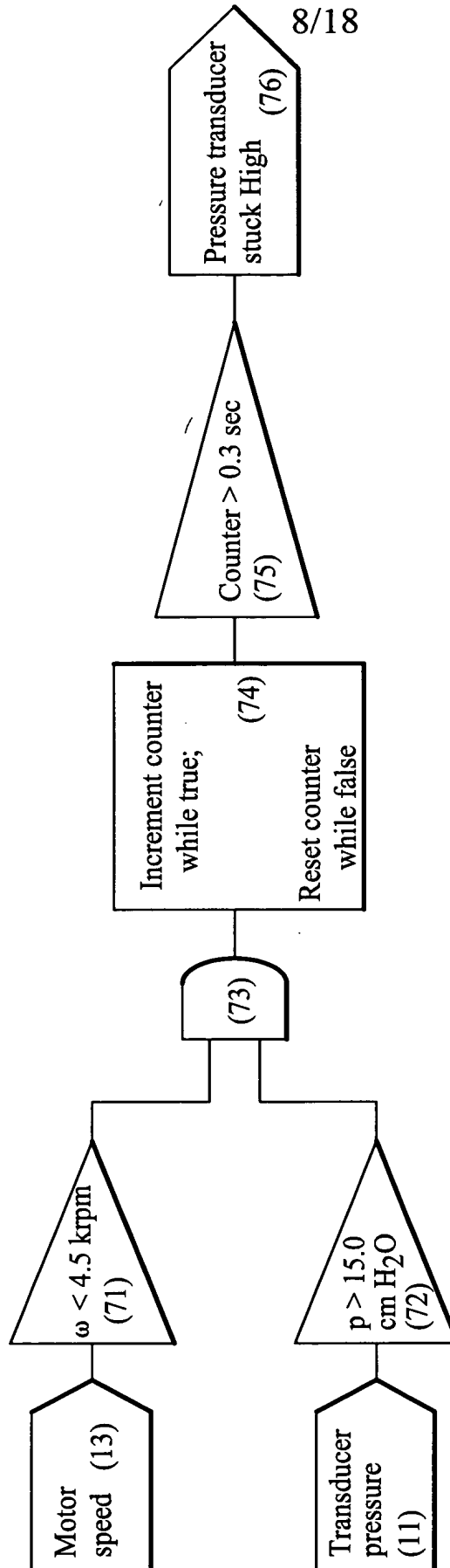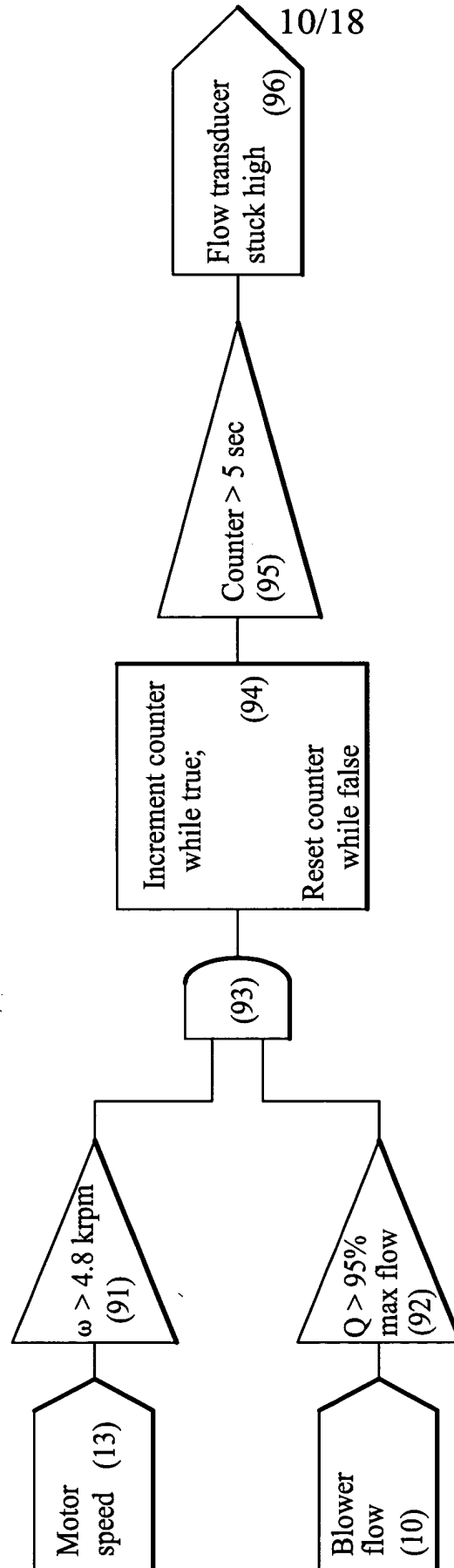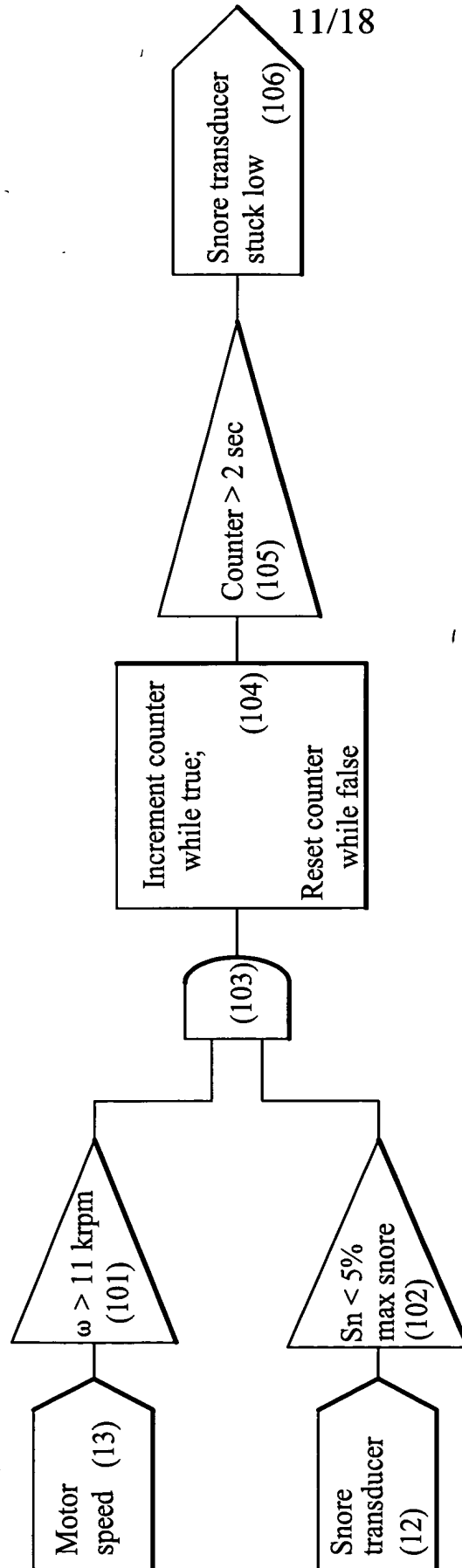
Figure 7:  *Detect Pressure Transducer Stuck High*

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Flow transducer stuck low (86)

Counter > 5 sec (85)

Increment counter while true;

(84)

Reset counter while false

(83)

ω < 4.8 krpm (81)

Q < 5% max flow (82)

Motor speed (13)

Blower flow (10)
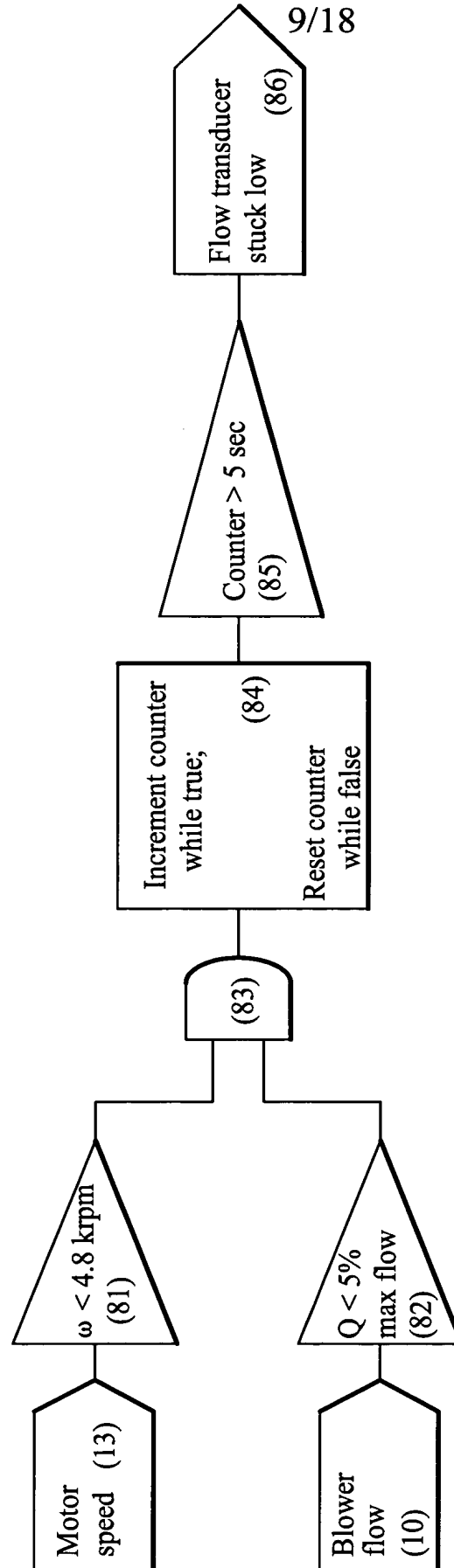
Figure 8: *Detect Flow Transducer Stuck Low*

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Flow transducer stuck high    (96)

Counter > 5 sec
(95)

Increment counter
while true;

(94)

Reset counter
while false

(93)

ω > 4.8 krpm
(91)

Q > 95%
max flow
(92)

Motor
speed   (13)

Blower
flow
(10)

Figure 9: *Detect Flow Transducer Stuck High*

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Snore transducer
stuck low    (106)

Counter > 2 sec
(105)

Increment counter
while true;    (104)

Reset counter
while false

(103)

ω > 11 krpm
(101)

Sn < 5%
max snore
(102)

Motor
speed   (13)

Snore
transducer
(12)

Figure 10:   *Detect Snore Transducer Stuck Low*

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Snore transducer stuck high (116)

Counter > 2 sec (115)

Increment counter while true; (114)

Reset counter while false

(113)

ω < 6 krpm (111)

Sn > 95% max snore (112)

Motor speed (13)

Snore transducer (12)
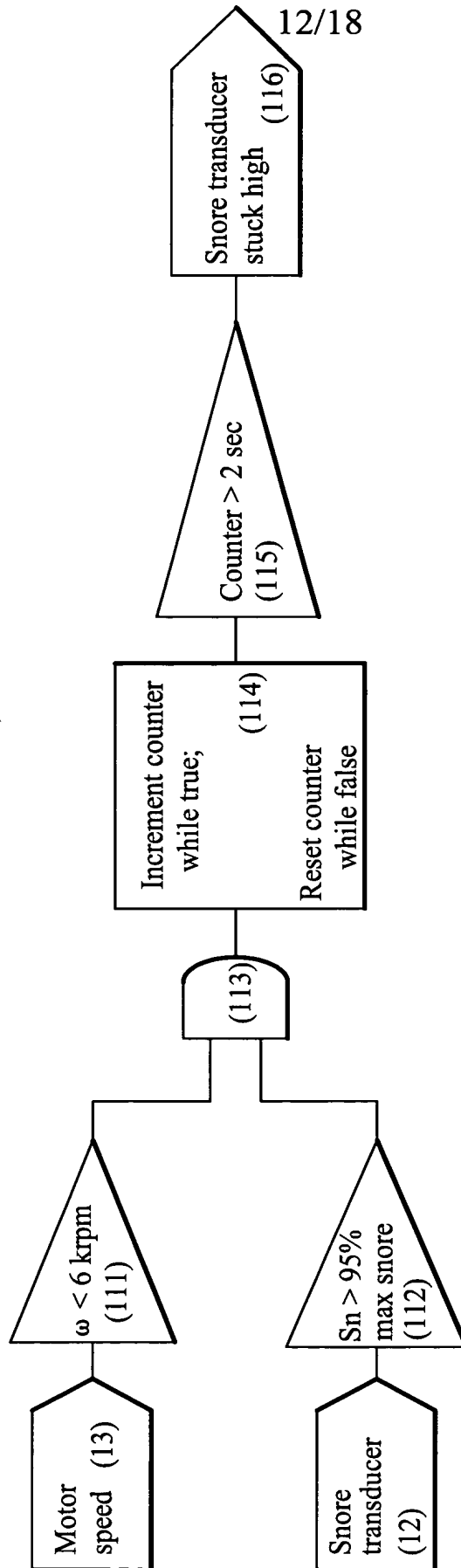
Figure 11: *Detect Snore Transducer Stuck High*

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Speed transducer stuck low (129)

Counter > 1 sec (128)

Increment counter while true; (127)

Reset counter while false

(126)

(125)

ω < 6 krpm (121)

I > 15% (122)

p > 8.0 cm H$_2$O (123)

Q > 75% (124)

Motor speed (13)

Motor drive (14)

Transducer pressure (11)

Blower flow (10)
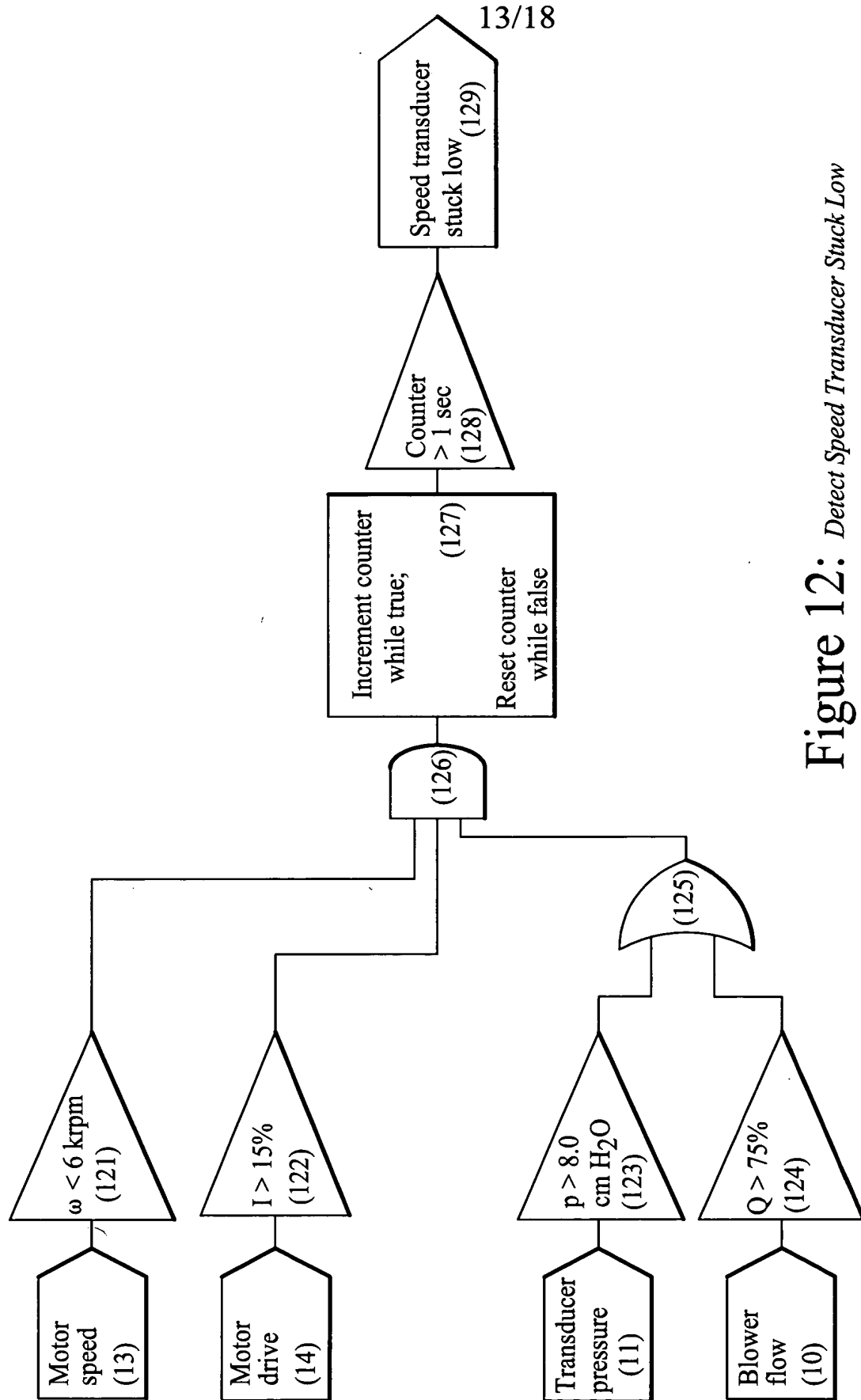
**Figure 12:** *Detect Speed Transducer Stuck Low*

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Speed transducer stuck high (139)

Counter > 1 sec (138)

Increment counter while true; (137)

Reset counter while false

(136)

ω > 18 krpm (131)

I < 5% (132)

(135)

p < 2.0 cm H$_2$O (133)

|Q| < 10 1/min (134)

Motor speed (13)

Motor drive (14)

Transducer pressure (11)

Blower flow (10)
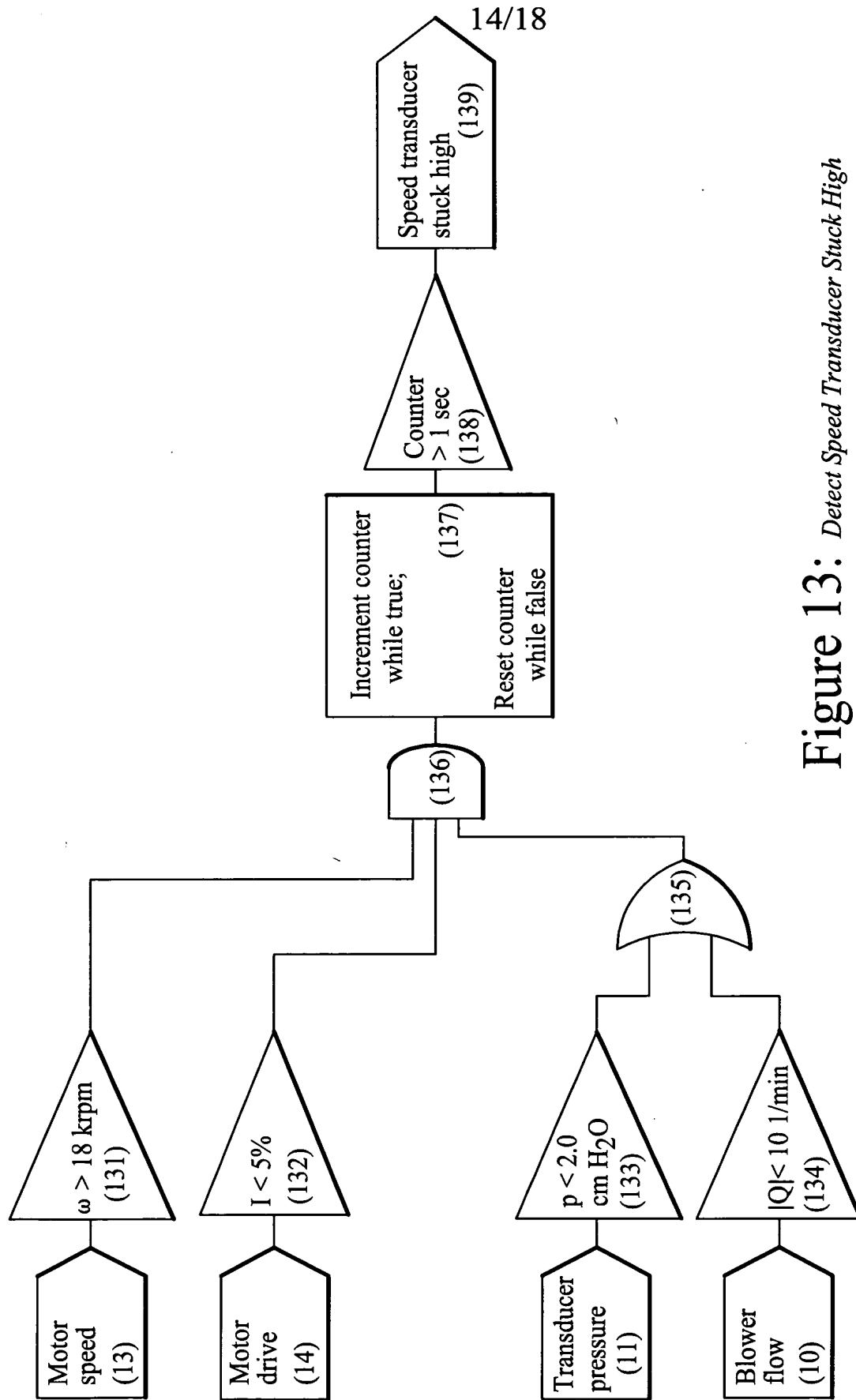
Figure 13: *Detect Speed Transducer Stuck High*

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Motor stalled (146)

Counter > 0.2 sec (145)

Increment counter while true; (144)

Reset counter while false

(143)

ω < 4.5 krpm (141)

I > 80% max (142)

Motor speed (13)

Motor parameter (14)
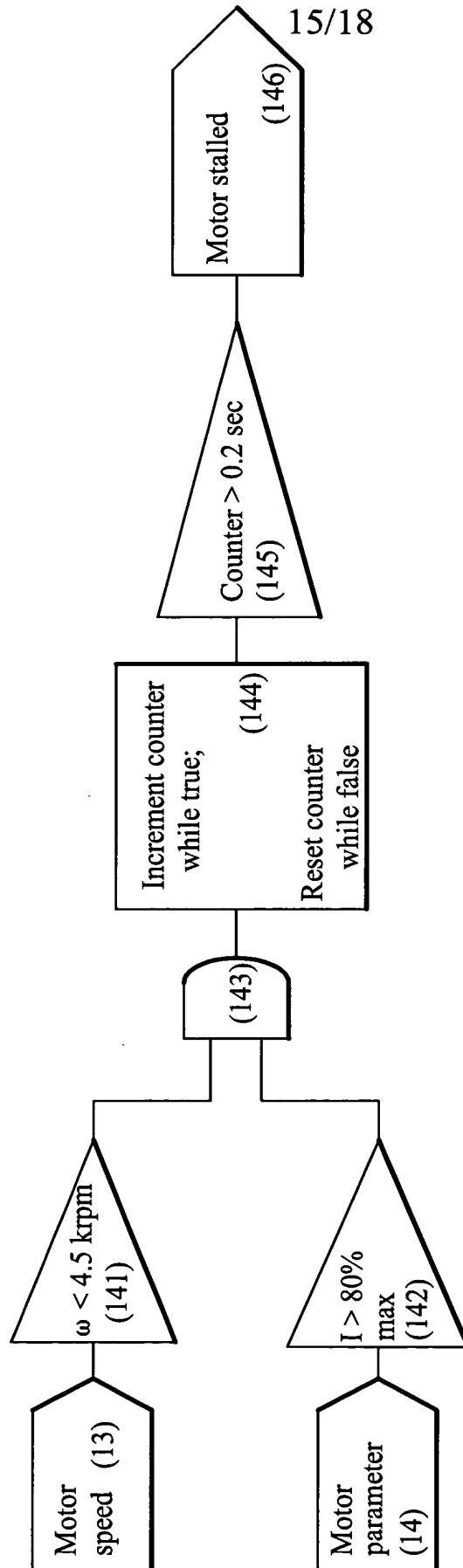
Figure 14: *Detect Stalled Motor*

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Restricted motor (156)

Counter > 30 sec (155)

Increment counter while true; (154)

Reset counter while false

(153)

ω <15 krpm (151)

I >95% max (152)

Motor speed (13)

Motor parameter (14)

Figure 15: *Detect Restricted Motor*

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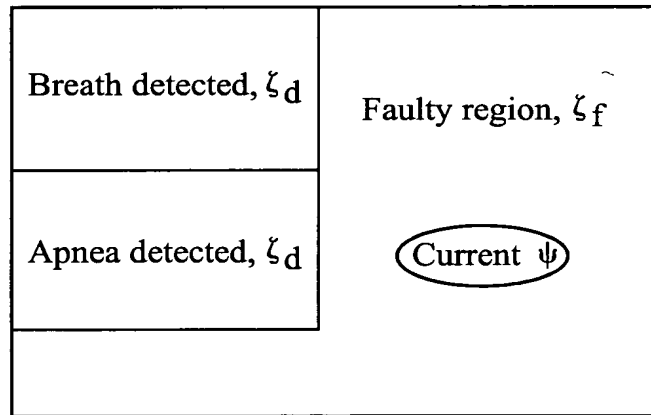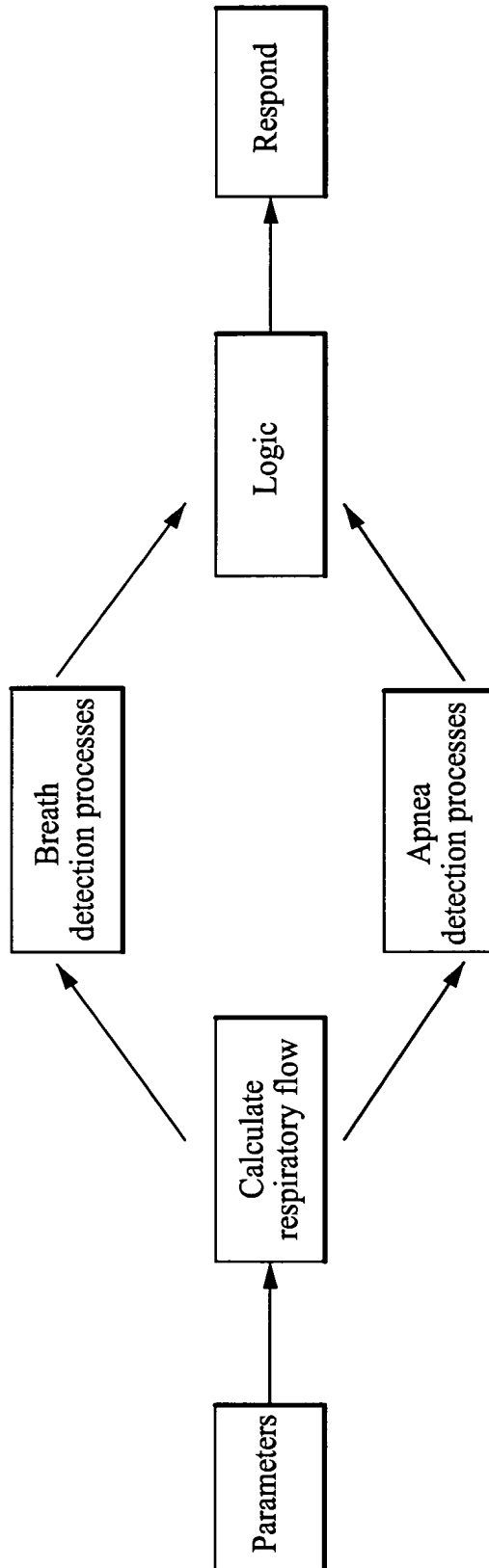| Breath detected, $\zeta_d$ | Faulty region, $\zeta_f$ |
| Apnea detected, $\zeta_d$ | $\boxed{\text{Current } \psi}$ |

**Figure 16:** *Software fault*

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Figure 17:  *Software fault detection processes*